BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W.   WASHINGTON, D. C. 20024

B70 05003

SUBJECT: Automated Leak-Detection System for Manned Interplanetary Spacecraft - Case 103-7

DATE: May 5, 1970

FROM: R. N. Kostoff

ABSTRACT

An externally mounted system of pressure gages that is capable of locating spacecraft leaks of 0.1 slug per day has been devised. These pressure gages are required to have a threshold detection pressure of 10^{-11} mm Hg, a figure that is well within the range of standard ionization gages. One pressure gage, located 30 feet above the vehicle surface and separated 40 feet from its nearest neighbor, is necessary for monitoring 300 square feet of vehicle surface. These figures strictly apply to a manned interplanetary vehicle, where the external ambient pressure is effectively zero. For an earth orbital vehicle with non-negligible external ambient pressure, the system is only reasonable for vehicle wake region operations. In the vehicle forebody region, facing the flow of background molecules, an inordinate number of gages are required to achieve acceptable signal/noise ratios.

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(NASA-CR-109999) AUTOMATED LEAK DETECTION SYSTEM FOR MANNED INTERPLANETARY SPACECRAFT (Bellcomm, Inc.) 10 p

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MEMORANDUM FOR FILE

Introduction

In a long duration manned mission, leakage of gas from the spacecraft may become a major expendables problem. The need arises for a simple system which can detect the location of leaks, so that they may be rapidly repaired. One such system will now be described.

Figure 1 shows a schematic of the detection system. Low-pressure ion gages, whose output signals are directly proportional to the magnitude of impinging molecular flux, are mounted in a symmetrical pattern at a uniform distance from the spacecraft outer skin.* When a leak occurs, gages in its vicinity respond with a signal emission. It is possible, by taking ratios of these signals, to "triangulate" and pinpoint the leak location. In practice, the magnitude of the signals will be fed into an onboard computer, and the coordinates of the leak will be obtained.

Now, the determining equations will be derived. Following this, the number of gages necessary to monitor a selected area of vehicle surface will be computed, as well as the proper gage-vehicle surface separation distance. For purposes of simplicity, a flat surface will be the representative geometry. Application of the technique to a particular curved surface is straightforward.

Analysis

Figure 2 shows a section of the flat surface with a triad of gages. The leak is assumed to be located in the triangle whose vertices are the gage projections on the surface. Flow from the hole is assumed to be effusive; i.e., it obeys a Lambert cosine law intensity distribution.

Figure 3 shows the leak-gage geometry:

*A typical ion gage, the inverted Bayard-Alpert gage, is described in Santeler, D. J., "Vacuum Technology and Space Simulation," NASA SP-105, 1966

R_1 is the distance from the leak to gage 1

R_2 is the distance from the leak to gage 2

R_3 is the distance from the leak to gage 3

ϕ_1 is the angle between R_1 and the surface normal

ϕ_2 is the angle between R_2 and the surface normal

ϕ_3 is the angle between R_3 and the surface normal

Θ_2 is the angle between $R_1 \sin \phi_1$ and $R_2 \sin \phi_2$

Θ_3 is the angle between $R_1 \sin \phi_1$ and $R_3 \sin \phi_3$

L is the gage spacing

H is the distance from the gage to the surface along a surface normal

The following six geometrical relations hold:

$$R_1 \cos \phi_1 = H$$

$$R_2 \cos \phi_2 = H$$

$$R_3 \cos \phi_3 = H$$

$$(R_1 \sin\phi_1)^2 + (R_2 \sin\phi_2)^2 - (2R_1R_2 \sin\phi_1 \sin\phi_2) \cos (\Theta_2) = L^2$$

$$(R_2 \sin\phi_2)^2 + (R_3 \sin\phi_3)^2 - (2R_2R_3 \sin\phi_2 \sin\phi_3) \cos (\Theta_3 - \Theta_2) = L^2$$

$$(R_1 \sin\phi_1)^2 + (R_3 \sin\phi_3)^2 - (2R_1R_3 \sin\phi_1 \sin\phi_3) \cos (2\pi - \Theta_3) = L^2$$

The ratio of gage signals, obtained by taking the ratio of molecular fluxes at the gage, is given by:

$$\frac{S_{G1}}{S_{G2}} = \left(\frac{R_2}{R_1}\right)^2 \frac{\cos \phi_1}{\cos \phi_2}$$

$$\frac{S_{G1}}{S_{G3}} = \left(\frac{R_3}{R_1}\right)^2 \frac{\cos \phi_1}{\cos \phi_3}$$

where

S_{G1} is the output signal of gage 1,

S_{G2} is the output signal of gage 2,

S_{G3} is the output signal of gage 3.

The above eight equations are solved simultaneously to yield R_1, R_2, R_3, ϕ_1, ϕ_2, ϕ_3, θ_2 and θ_3.

Now the approximate gage spacing will be obtained. Consider Figure 4. Here, the leak is assumed to be located directly under one of the gages, say gage 1. One constraint is that in this configuration, the leakage should be detectable by gages 2 and 3. Thus, the molecular flux impinging on gages 2 and 3 will be arbitrarily prescribed as at least two orders of magnitude above the threshold flux of gages 2 and 3. A second constraint is that the gage spacing should be as large as possible, in order to minimize the number of gages. These two constraints are coupled in the following manner: The flux measured by an omnidirectional gage at point R, ϕ is, for effusive flow

$$F = \left(\frac{M}{\pi R^2}\right) \cos \phi$$

where

F is the molecular flux at R, ϕ,

M is the mass flow from the leak,

R is the distance between gage 2 and the leak,

ϕ is the angle between $\bar{R}$ and the surface normal.

The equation of the constant measured flux line (F=const.) becomes:

$$R = R_o \sqrt{\cos \phi}$$

where R_o is the value of R when ϕ=0.

The distance between the constant flux line and the leak in a direction parallel to the surface is R sin ϕ, or $R_o \sin \phi \sqrt{\cos\phi}$.

This distance is greatest when:

$\phi = \phi_M = \tan^{-1} \sqrt{2}$, or $\frac{L}{H} = \sqrt{2}$

The following values are assumed:

$M = .1$ slug/day ~ 40 gms/day

$F = 24 \cdot 10^{-12}$ gms/cm^2-sec (mass flux at $P = 10^{-9}$ mm Hg)

This results in:

$R_o = 1.73 \cdot 10^3$ cm

$H = 10^3$ cm

$L = \sqrt{2} \cdot 10^3$ cm

Thus, the gage spacing is $\sim$40 ft. and the gage-surface distance is $\sim$30 ft. From the geometry, for many gages, 1 gage is necessary to monitor an area equal to that of a gage-bounded triangle, or, in this case, an area of approximately 300 ft^2.

Applicability

Such a system is strictly applicable only to interplanetary spacecraft. For an earth-orbiting vehicle, the assumption of negligible background molecular flux is generally not valid. A gage located in the spacecraft forebody region would experience a large molecular flux, while one located in the wake and thereby shielded from the oncoming molecular stream would experience a negligible background molecular flux. At 700 Km altitude, where the ambient pressure is about 10^{-9} mm Hg, the maximum dynamic pressure which a gage in the forebody region would see is about 10^{-7} mm Hg. To retain a signal/noise ratio of one hundred, the number of gages required in this region (facing the flow) is three orders of magnitude greater than that required in the wake region or in interplanetary flight. Thus, the above described system is reasonable only for wake region operation. A modified system capable of operation in the forebody region has not been investigated.

R N Kostoff

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Attachments
Figures 1-4

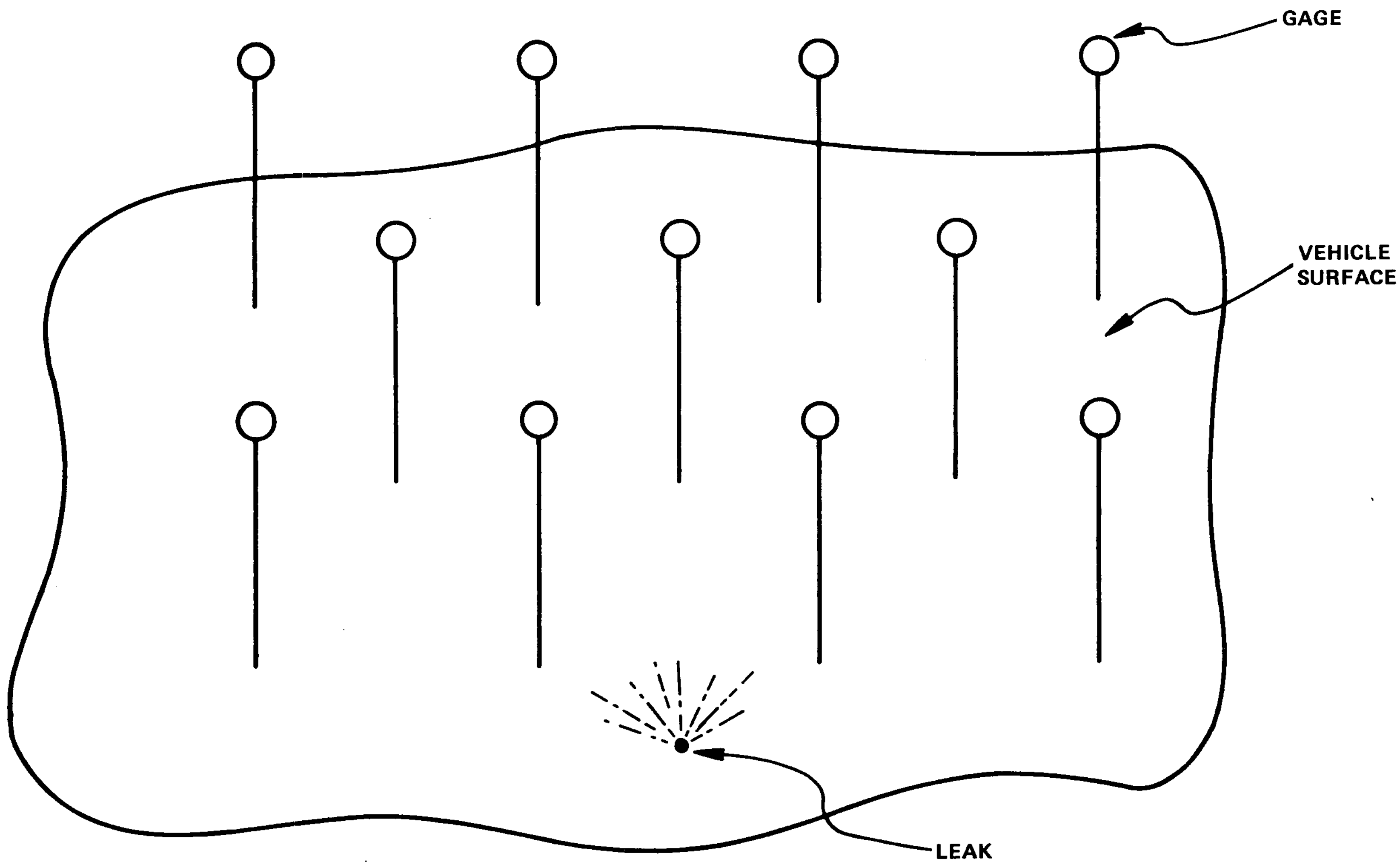

FIGURE 1. LEAK-DETECTION SYSTEM SCHEMATIC

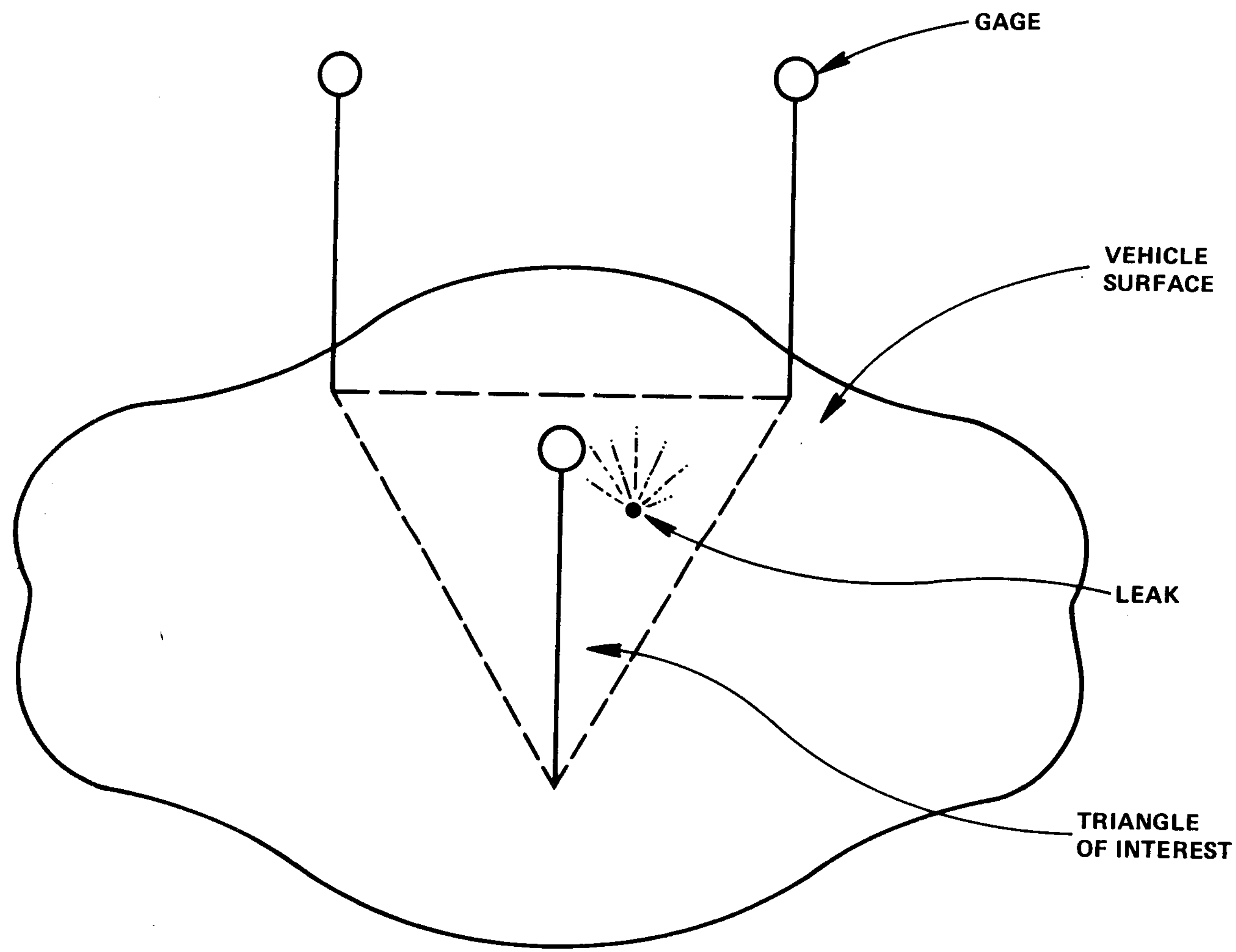

FIGURE 2.

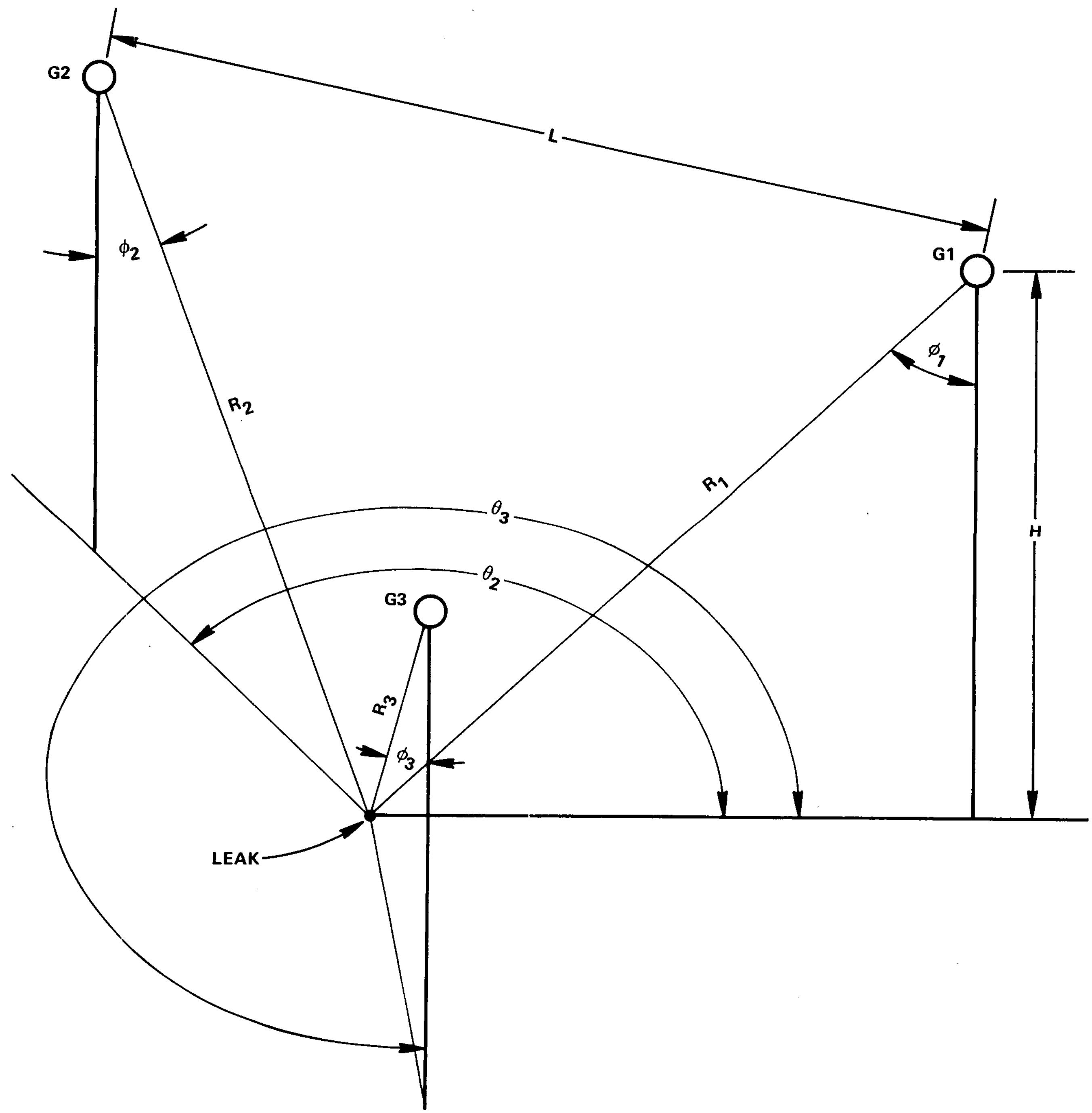

FIGURE 3. LEAK-GAGE GEOMETRY

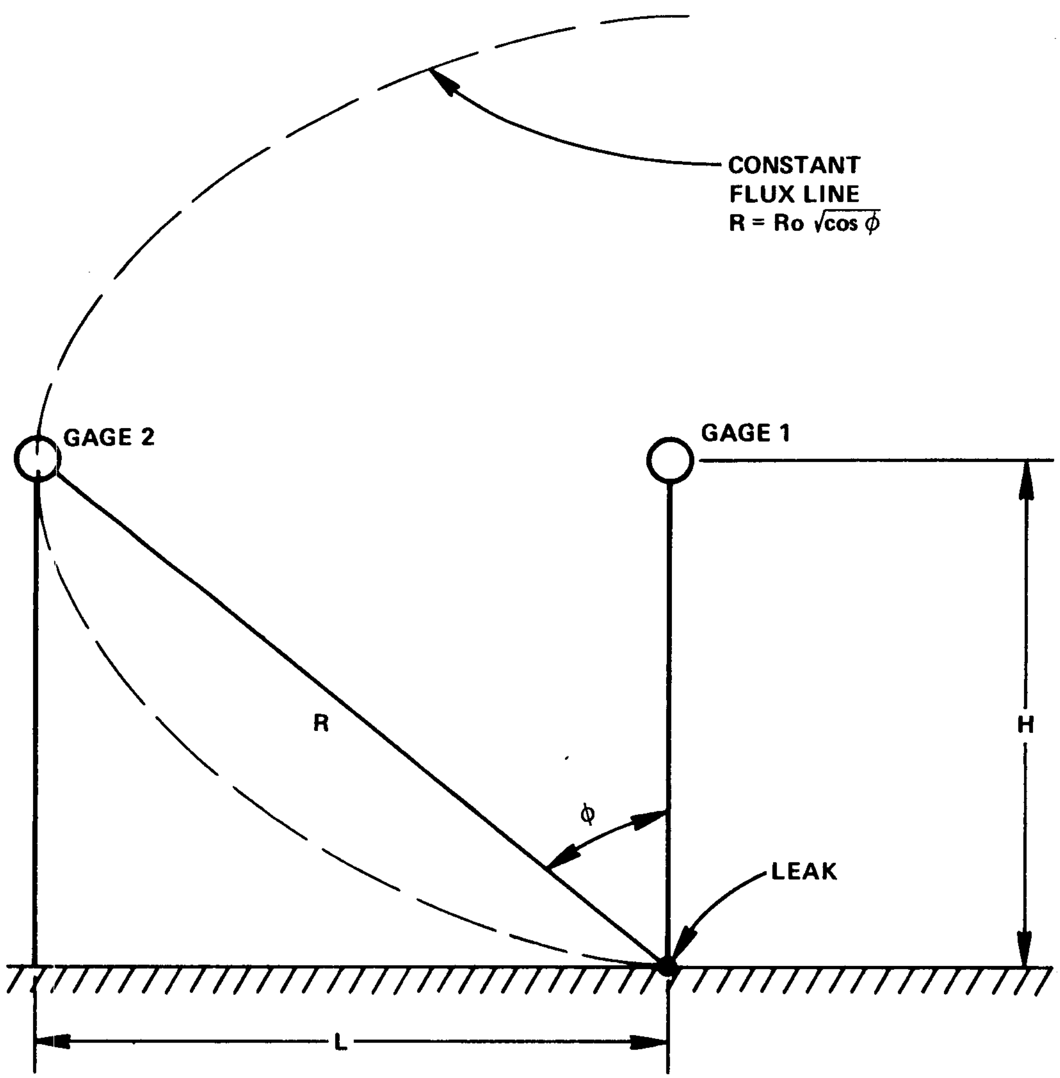

FIGURE 4.

BELLCOMM, INC.

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